

Beyond Grain Size: Environmental and Seasonal Drivers of Surf Smelt and Sand Lance Spawning Habitat Use in Snohomish County

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Abstract:

This study examines how sediment grain size, substrate composition, seasonality, and physical beach characteristics influence spawning presence of Pacific sand lance (*Ammodytes personatus*) and surf smelt (*Hypomesus pretiosus*) across three Snohomish County beaches spanning 2018–2026. Using grain-size analyses, multivariate and logistic regression modeling, and seasonal presence data we evaluated whether local substrate conditions predict egg occurrence. Although sediment composition differed significantly among sites, no individual grain-size category or overall substrate mixture reliably predicted spawning. Additionally, individual sediment classes and overall composition showed no significant ability to predict spawning, however, several grain size mixtures emerged as influential. Both species modeled higher occurrences on substrates containing coarse sands and small pea gravel and had negative associations with larger pea-gravel fractions. These patterns suggest forage fish respond to specific sediment blends rather than single grain size categories.

Seasonality emerged as the strongest statistical driver of occurrence: surf smelt spawned predominantly in fall, and sand lance exclusively in winter. Additional environmental factors described in regional literature including beach aspect, fetch, sediment temperature, and site position within drift cells likely contribute to the low spawning intensity observed in Snohomish County. Comparisons with highly productive beaches elsewhere in Puget Sound suggest that physical site characteristics play a larger role than sediment alone in determining spawning suitability. Together, these findings underscore the importance of broad physical and environmental characteristics in shaping forage fish spawning habitat use and highlights the need for future monitoring to incorporate geomorphic and thermal variables alongside sediment analyses.

Key Take Aways:

- Historically, forage fish experience fluctuations in populations, several environmental and behavioral drivers impact habitat usage, and even with suitable substrate only spawn on beaches 30% of the time (Quinn et al., 2009)
- Howarth Park is Snohomish County's most productive beach, likely due to characteristics like substantial fetch that support medium to high wave action and north facing beach aspect conferring low solar radiation and sediment temperatures improving egg mortality.
- In Snohomish County, surf smelt spawn predominately in the fall and winter and sand lance spawn exclusively in the fall. Both populations showed positive associations with small pea gravel and coarse sands.

Background:

This report examines how grain size, sediment composition, seasonality, and beach characteristics influence the occurrence of Pacific sand lance (*Ammodytes personatus*) and surf smelt (*Hypomesus pretiosus*) eggs across three Snohomish County beaches: Picnic Point, Meadowdale, and Howarth Park. It is important to note that Howarth was renourished in 2016 and that Meadowdale underwent a restoration to remove a culvert conferring normal sedimentation activity. The Meadowdale project started in 2020 and was completed in 2023; the effects of the restoration are still being monitored but the recruitment and retention of sand have been high since removing the bottle neck.



Fig 1. Pacific sand lance (*A. personatus*)

Photo Credit: Snohomish County Marine Resources Committee, Forage Fish Spawning Surveys.

Image asset: <https://www.snocomrc.org/projects/forage-fish-spawning-surveys/>



Fig 2. Surf smelt (*H. pretiosus*) Photo taken by J. Gaydos

Photo Credit: SeaDoc Society, Surf Smelt Recreational Harvest Study. <https://www.seadocsociety.org/blog/surf-smelt-study/>

Image asset: <https://images.squarespace-cdn.com/content/v1/5b071ddea2772cebc1662831/1527209241193-LR2WGVY051VV2UOACZY2/image-asset.jpeg>

Forage fish (FF) species play a critical ecological role as middlemen in the Puget Sound food web, supporting marine mammals, seabirds, and salmon populations (Washington Department of Fish & Wildlife, n.d.). It is thought that 60% of coho salmon diets are comprised of forage fish and their eggs (Snohomish County Marine Resources Committee, 2026). Due to their role in the ecosystem, they are considered indicators of healthy and productive marine ecosystems and understanding their spawning habitat use is important for restoration planning, beach management, and environmental monitoring.

Previous studies show that sand lance (SL) typically prefer fine sand (0.2–0.4 mm) and spawn primarily in winter, while surf smelt (SS) prefer sand–gravel mixtures (1–7 mm) and spawn year-round depending on geographical location (Snohomish County Marine Resources Committee, 2021).

However, many apparently suitable beaches do not host spawning, suggesting environmental factors beyond substrate may drive occurrence. This study aims to understand these environmental drivers behind forage fish habitat usage on Snohomish County beaches and in the greater Puget Sound.

Table 1 Fig 3. Spawning patterns of surf smelt and sand lance (Snohomish County Marine Resources Committee, 2021).

Data:	Surf Smelt	Sand Lance
North sound spawning	Summer	Winter
South Sound Spawning	Winter	Winter
Tide Preference	+7 tides	+5 tides
Substrate Preference	Sand/gravel mix (1-7 mm diameter)	Prefer sand (0.2-0.4 mm diameter)
Other Knowns	Need shade	Spawn in water/low beach

Snohomish County is not considered prolific spawning ground for forage fish as only 37 detections have been recorded since 2018 across all three sites, most of these detections taking place at Howarth Park. It should also be noted FF juveniles and adults have been reported in the Snohomish County estuary predominately in spring and summer for SL and year-round for SS, but further collaboration is needed to analyze the populations utilizing these different habitats investigating when and for what purposes.

While detections are low overall, Snohomish County beaches play a pivotal role in the continuation of SS spawning in the winter as observations by other Marine Resources Committees (MRCs) report predominately summer spawning. This continuation of spawning is important to keep overall recruitment of forage fish high, helping to contribute to ecosystem stability. This is the ecological phenomenon of the portfolio effect in action as this seasonal diversity can help stabilize populations shielding them from environmental shocks like storms or temperature shifts that can raise egg mortality. This stabilizing and resilience-boosting outcome of having multiple species or different spawning times maintains overall ecosystem function even when certain populations decline and is the basis of the portfolio effect. With this continuation of spawning supporting healthy ecosystems my goal was to not only identify desirable grain sizes and seasonality of local spawning but also seek to determine why our beaches may not be utilized by FF populations and what actions we can take to improve and increase usage of local beaches.

Methods:

Sediment composition data were determined by using grain size analysis from three Snohomish County beaches from 2018–2026. Data from Howarth Park was available only through 2023 due to discontinued grain-size sampling in recent years. Additionally, data from Howarth Park spanning 2018-2020 had a North and South reference point selected from WDFW sites to represent MRC samples for those years. Lastly, during the Meadowdale restoration sampling was sporadic throughout 2021 and 2022. Overall, the data span 2018-2026 with the caveats above.

Forage fish spawning surveys utilized WDFW protocols. Monthly samples are taken along two 100 foot transects. Sediment is collected from the top 2-3 inches of the beach, where eggs would be deposited at the “dan band” (high tide mark or wrack line). The first step after collection is to sieve the sediment sample through progressively finer sieves. Only the material collected in the 0.5 mm sieve is retained and added to a hydro-cyclone, called the blue vortex, that concentrates the light material. This material is then collected and retained for laboratory analysis to identify and count the eggs (Dionne, 2015; Moulton & Penttila, 2006).

Grain size analysis data was paired with its respective presence absence data and combined into a master excel file where 353 grain size data points are paired with presence absence data spanning 2018 to 2026. I then used the Wentworth scale, a geological particle size classification tool to classify and combine the sieve groupings by their particle size into the WDFW forage fish sediment classes: mud, pure sand, pea gravel, medium gravel, coarse gravel, cobble, and gravel boulders. I was then able to determine individual percentages for sediment categories as well as overall sediment composition for every sample.

To determine how substrate composition and grain size influence FF egg presence we used several complimentary statistical approaches. These analyses allowed us to first test whether sampling sites differed in substrate structure, whether individual grain size categories or combined sediment compositions were associated with egg presence, and lastly whether seasonal variation contributed to changes in substrate patterns or egg occurrence. Using a blend of both parametric and non-parametric approaches allowed us to match each analysis method to the structure of the data: parametric models were used to quantify continuous substrate–presence relationships, while non-parametric tests were applied where assumptions were not met and when small seasonal categories were being used. This ensured robust inferences despite the small overall dataset and low presence count.

Workflow and Analysis used:

1. Site-Level Variation in Substrate

MANOVA with Wilks' Lambda tested whether grain-size compositions differed among sites when all sediment variables were considered simultaneously.

2. Univariate Substrate Effects

One-way ANOVA tested whether individual grain-size categories differed between presence and absence samples.

3. Multivariate Substrate–Presence Relationships

PERMANOVA assessed whether full sediment composition predicted egg presence. Site was included as a filter.

4. Logistic Regression Models

Binomial GLMs modeled egg presence (0/1) using individual sediment fractions, grouped sieve sizes (#8 + #16 + #30), and combinations of substrate types (e.g., pure sand, pea gravel, medium gravel). Model comparisons used AIC, deviance, and significance of predictors.

5. Seasonal Effects

Pearson's Chi-Square and Fisher's Exact Tests evaluated whether presence varied by season. ANOVAs tested seasonal changes in substrate composition.

Aside from data collection and analysis I also took a qualitative approach and reached out to MRCs in Island, Skagit, and Clallam counties as well as several WDFW forage fish biologists. These correspondences, in tandem with literature reviews, were crucial and yielded much information aiding in analyzing Snohomish County beaches.

Results:

Sediment Composition Across Sites:

Pure sand was the most dominant substrate across all sites, while pea gravel was the most variable. MANOVA revealed highly significant differences between sites (p-values $\approx$ found **0.0000000000001134**) confirming distinct sediment distributions across sites.

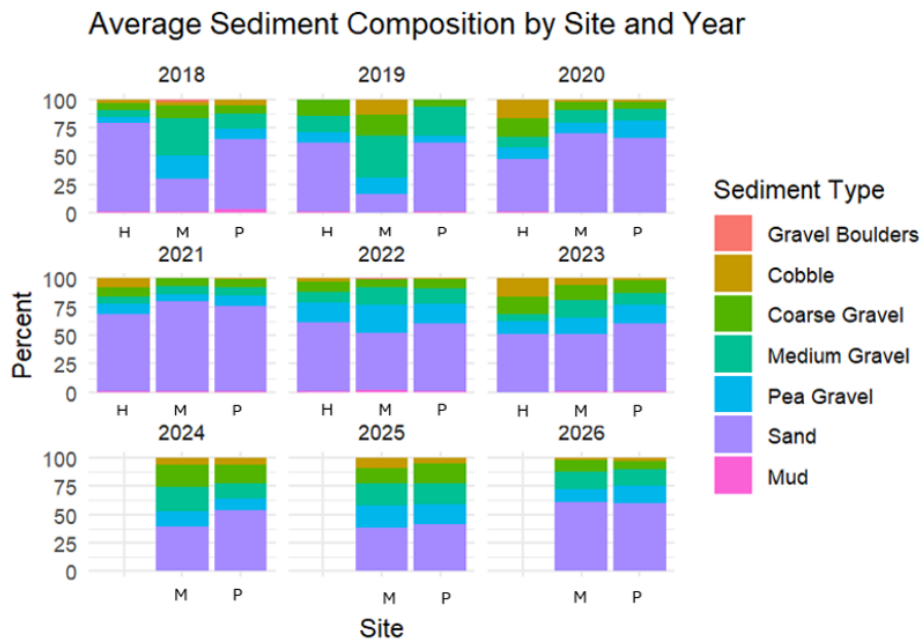


Fig 4. Average sediment composition is shown for each site, data ranges from 2018-2026 and 2018-2023 for Howarth.

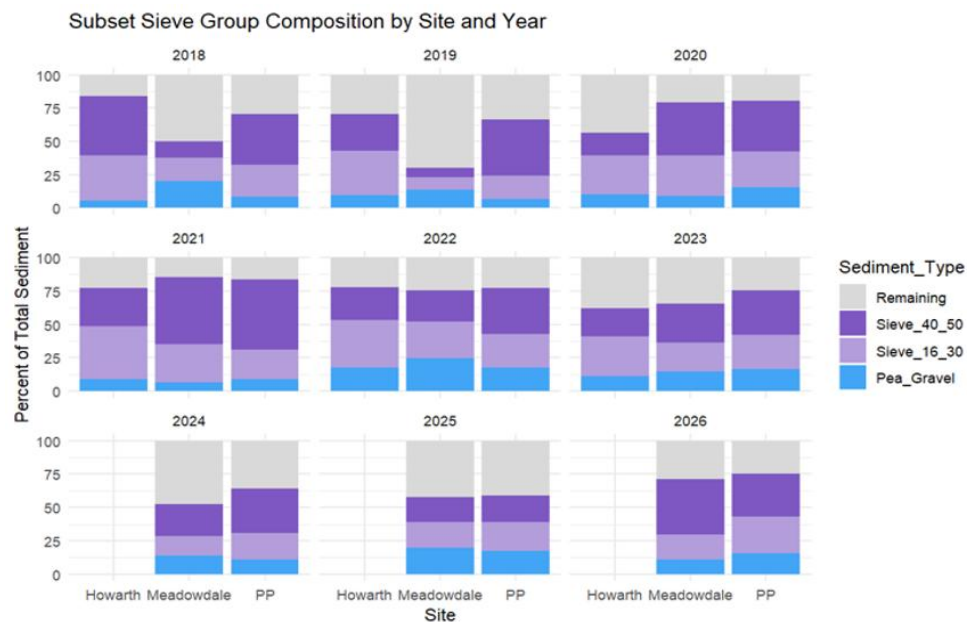


Fig 5. Average composition of coarse sands (16, 30), fine sands (40,50), and pea gravel are shown for each site, data ranges from 2018-2026 and 2018-2023 for Howarth.

See Appendix for Violin Plots representing sediment types broken down by category overtime (Figures 1-2)

Substrate Effects on Presence:

SL $R^2 = 0.00206$ indicates that sediment composition explains no variation in presence | SL $P = 0.501$

F value = 0.7186 for SL indicates no difference between sediment compositions with or without eggs present.

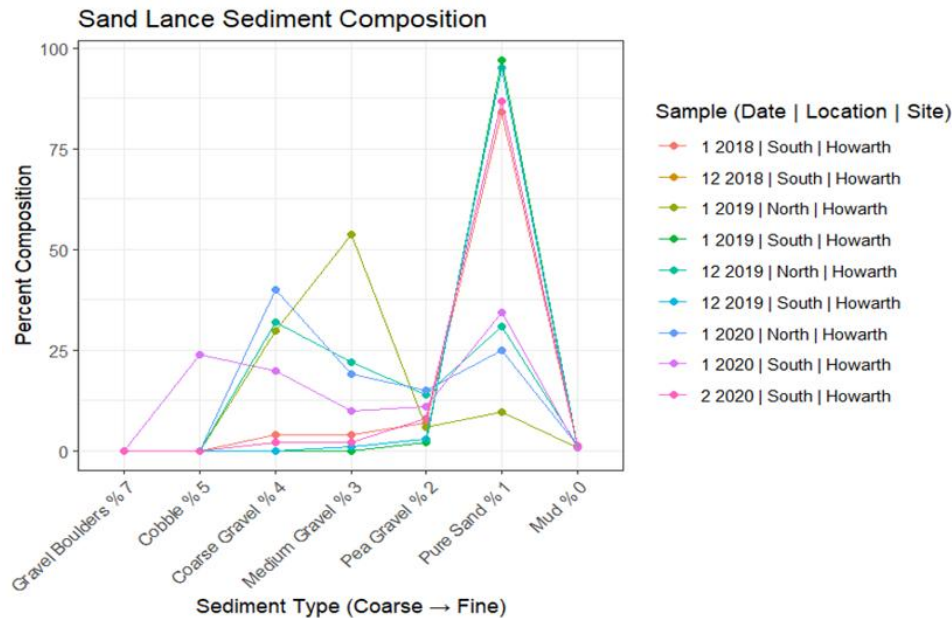


Fig 6. Sediment compositions when Sand Lance eggs were present 2018-2020.

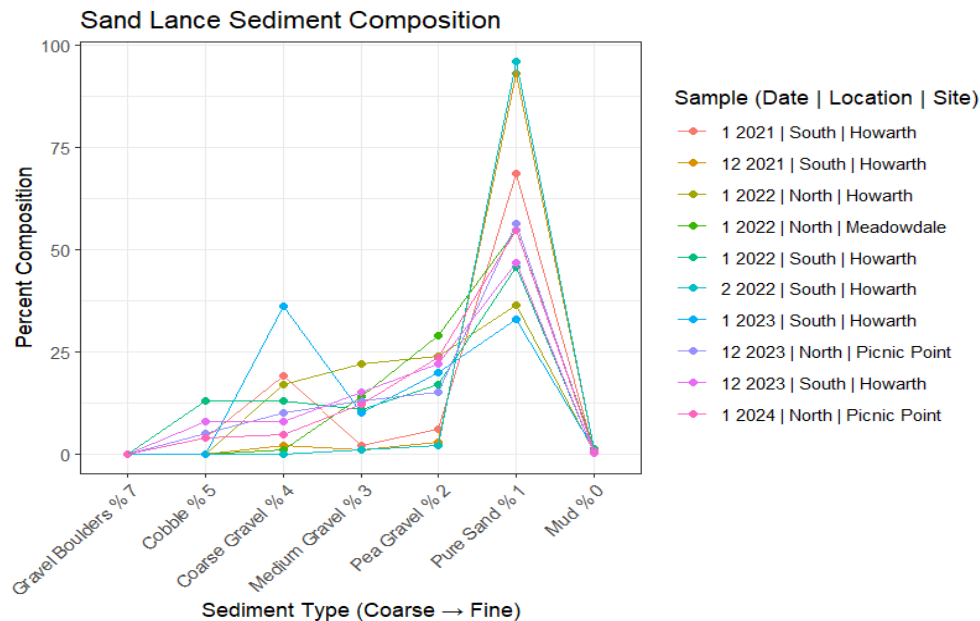


Fig 7. Sediment compositions when Sand Lance eggs were present 2021-2026

Sediment composition appears much more variable 2018-2020 and follows more of a trend 2021-2026 with the latter having consistently higher sand peaks and less variation in the medium to large grain size categories. Overall, 19 presence data points were found from 2018-2026, most of those occurrences being at Howarth.

SS $R^2 = 0.00535$ Sediment composition cannot explain or predict presence | SS p value = 0.16

F value = 1.8723 indicates mild difference for SS (there is more variation between presence absence data than there is within each respective group.)

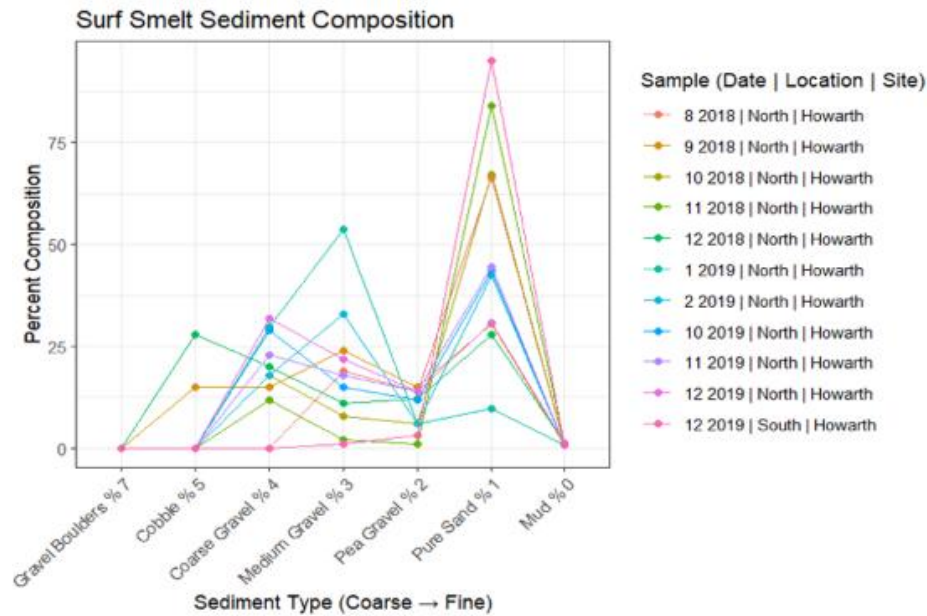


Fig 8. Sediment Composition when Surf Smelt were present 2018-2019

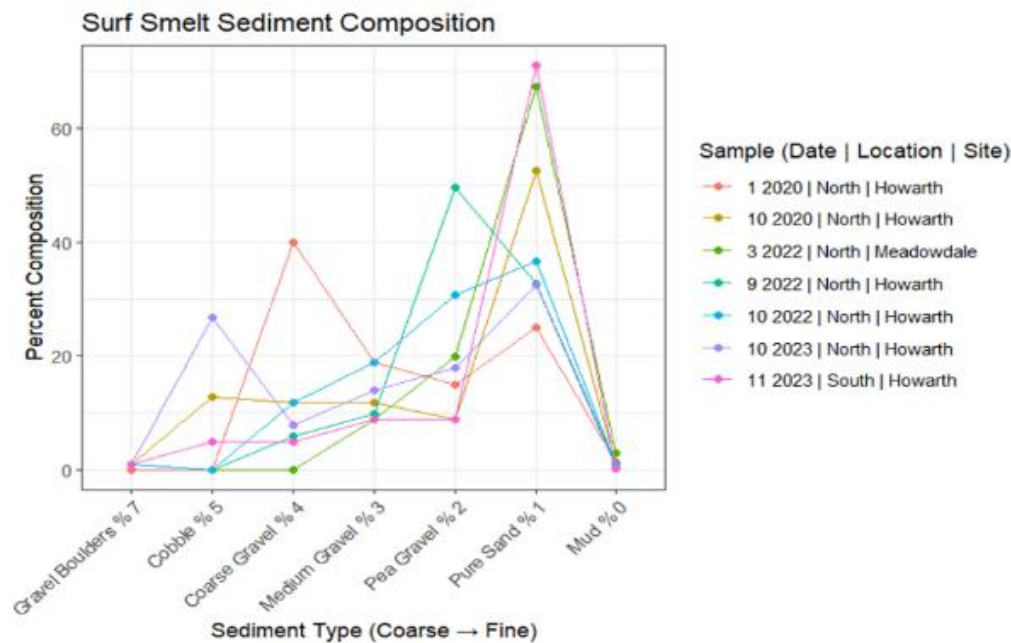


Fig 9. Sediment Composition when Surf Smelt were present 2020-2026

There were 18 presence data points that were found from 2018-2026 most of those occurrences being at Howarth North, it should also be noted that three samples had detections with both species simultaneously and were included on both species plots.

Surf Smelt Regressions:

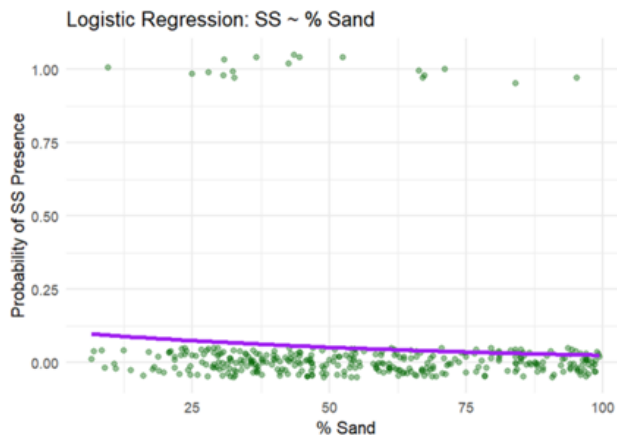


Fig 10. SS Logistic Regression, all sites, sand only

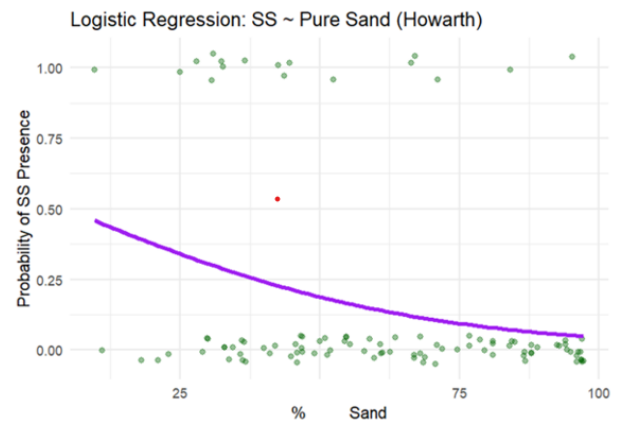


Fig 11. SS Logistic Regression, Howarth, Sand only

Sand alone predicts SS appearance negatively especially when site is filtered to Howarth only. With the addition of pea gravel and mostly medium gravel sand shows a weak but positive association with SS presence making medium gravel the strongest positive predictor of egg occurrence.

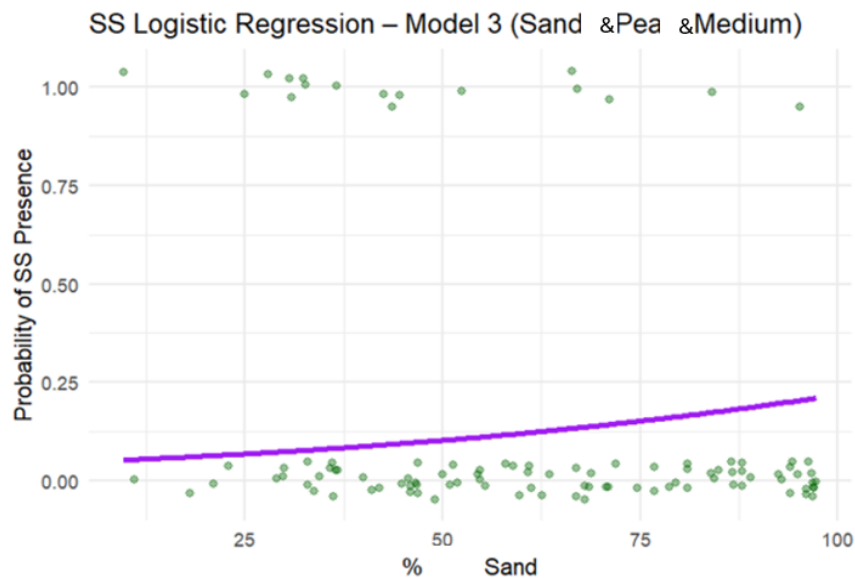


Fig 12. SS Logistic Regression Most Improved Model Fit Howarth only with Sand, Pea Gravel, and Medium Gravel effects

The AIC for Model 3 is 77.35 which lowered significantly from 90.79 in Model 2.

Medium Gravel $P = 0.003$

Sand Lance Regressions:

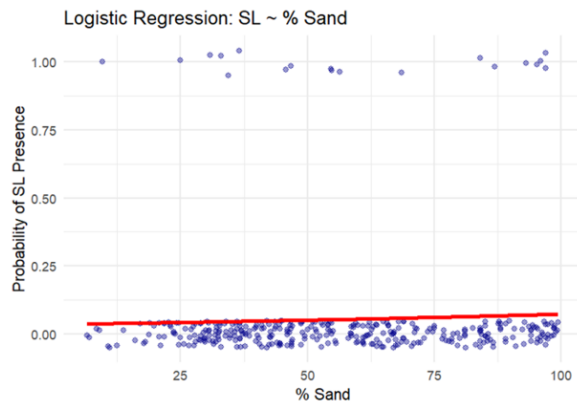


Fig 13. SL Logistic Regression, Howarth, sand only

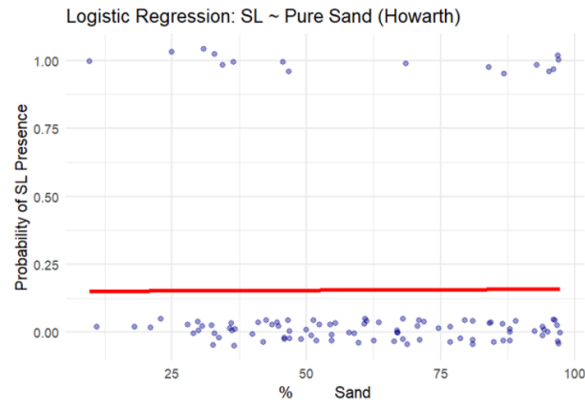


Fig 14. SL Logistic Regression, all sites, and only.

With all sites accounted for there is a slight positive relationship between sand percentage and SL presence. But once points from Meadowdale and Picnic Point are removed the graph becomes more neutral. The model is most improved with the addition of all the gravel types where a positive relationship between sands and sand lance presence is seen in Model 4.

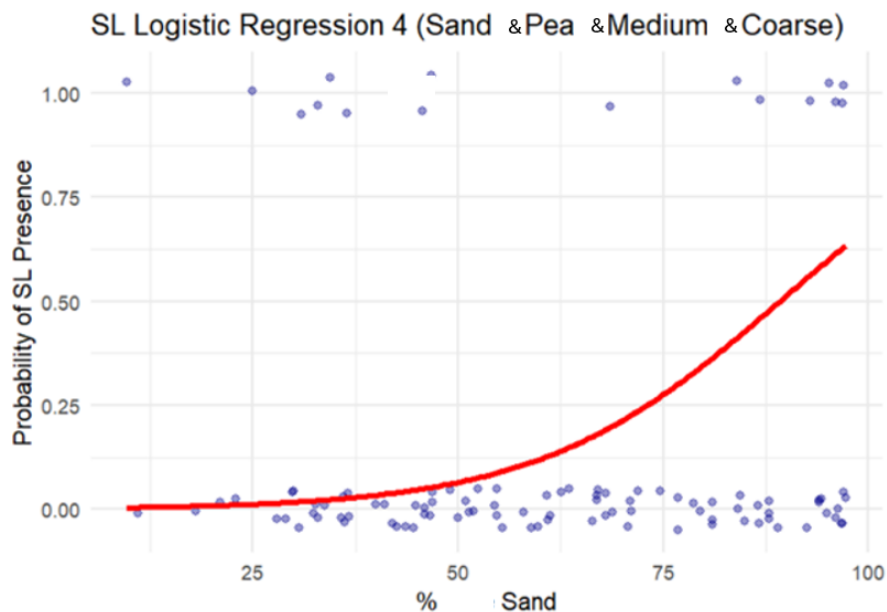


Fig 15. SL Logistic Regression Most Improved Model Fit Howarth only with Sand, Pea Gravel, Medium Gravel, and Coarse Gravel effects.

The AIC for Model 4 is 91.29 which lowered from 94.62 in Model 2.

Medium Gravel $P=0.042$

Coarse Gravel $P=0.081$ – Boarderline significance

Sieve Groupings and Combination Relationships:

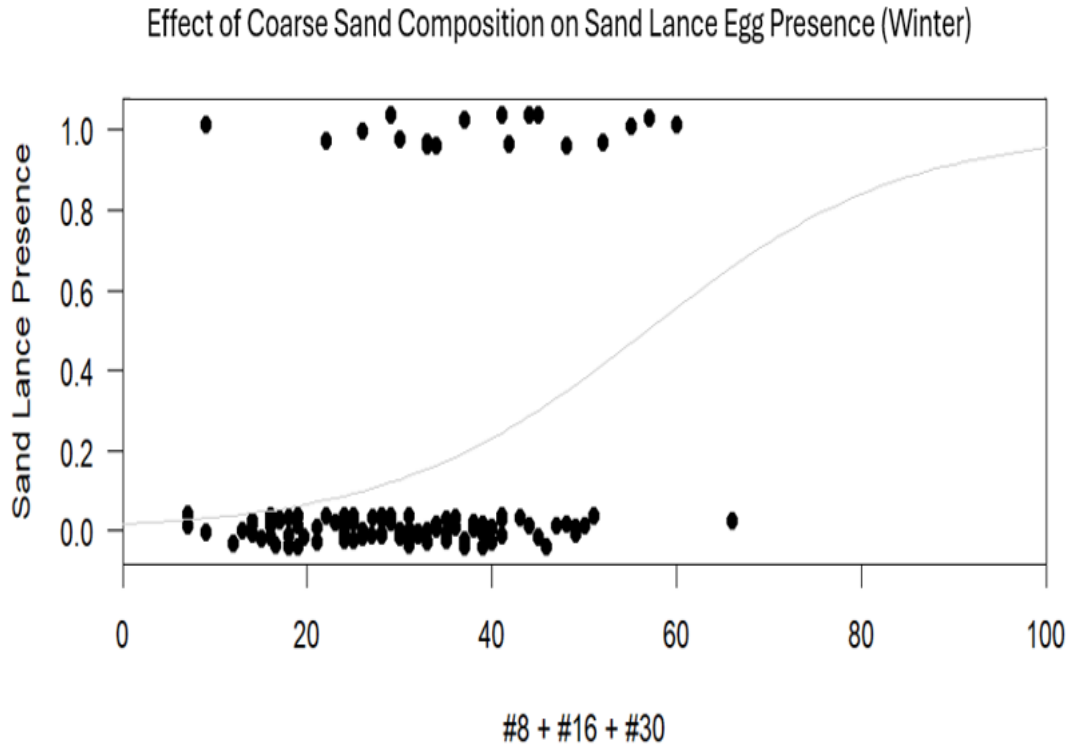


Fig 16. This regression shows the most improved model where coarse sands and pea gravel increase the probability of detecting Sand Lance eggs.

- There is a positive relationship when the three sieves numbers 8 (~2.36mm), 16 (~1.19mm), and 30 (~0.60 mm) are combined. As these increase in quantity so does the probability of eggs.
- The smallest sieve for pea gravel #8 strongly increases presence and there is a positive association with #16 and #30 (the coarse sands) as their addition helped improve model fit.
- #4 ~(4.75mm) the larger sieve size for pea gravel was identified as a negative association.
- The same trends have been identified for SS but are more subtle, and eggs occur less often when # 16 is present as well as #4.
- Fine grain sands were seen to not have an effect on presence on either species.

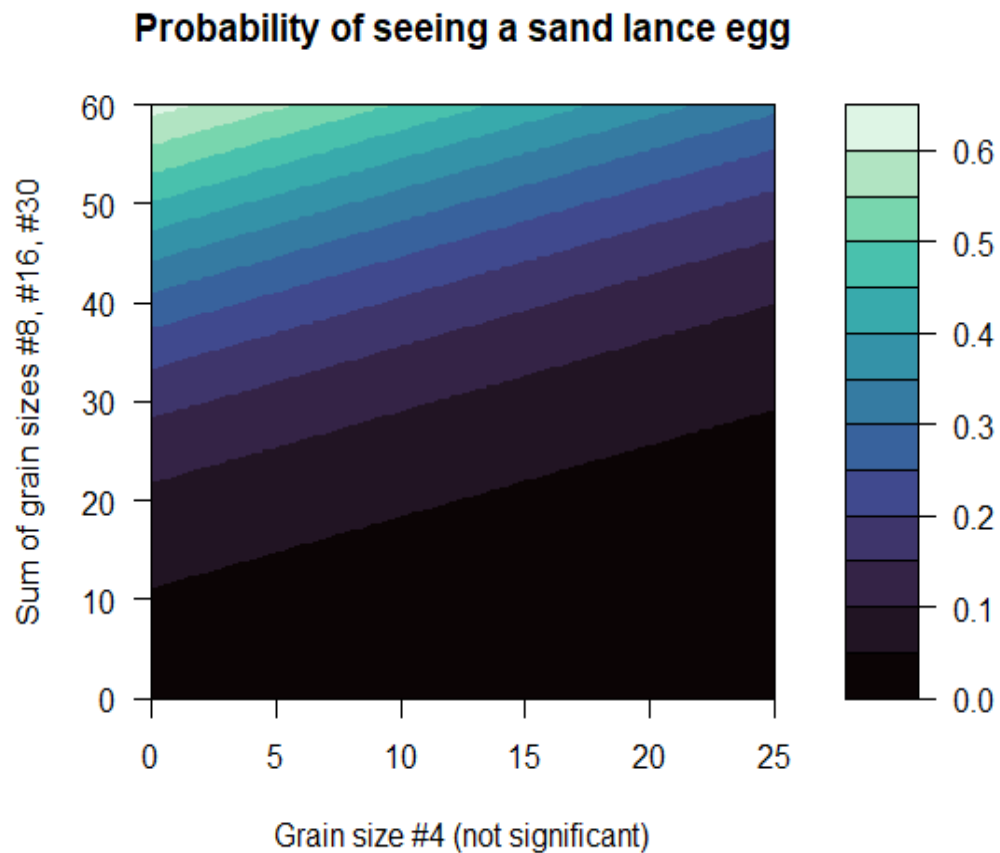


Fig 17. This contour plot represents the inverse relationship between both pea gravel types #4 (negative) and #8 (positive when coarse sands are present as well).

- The combination model of #4 and #8 was negative and significant for both species, a directly inverse relationship is seen between the two pea gravel sieves.
- In the contour plot when there is a more #4, there is more black (zero probability), but when there is increasing #8, 16, and 30 there is more light blue (trending towards one or high probability) which showcases this inverse relationship.
- Note that the negative driver of larger pea gravel #4 cancels out the positive association with small pea gravel #8 in the combination model.

Seasonality:

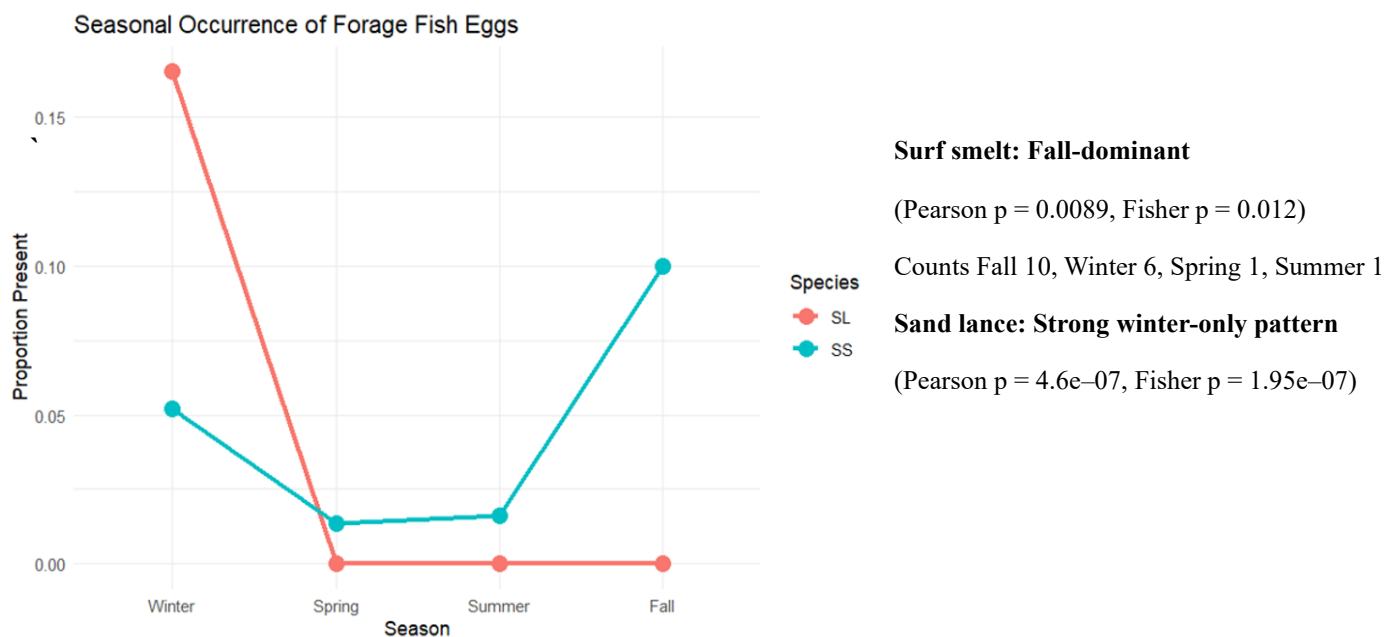


Fig 18. The proportion values represent how often we detect eggs in each season relative to the total amount of samples taken a season and tells us the frequency of egg occurrence across seasons.

Table 2 Fig 19. This table shows significant or borderline significant seasonal changes in substrate.

Substrate	ANOVA P-Value
Mud	0.871
Pure Sand	0.053
Pea Gravel	0.857
Medium Gravel	0.366
Coarse Gravel	0.072
Cobble	0.0000175
Gravel Boulders	0.229

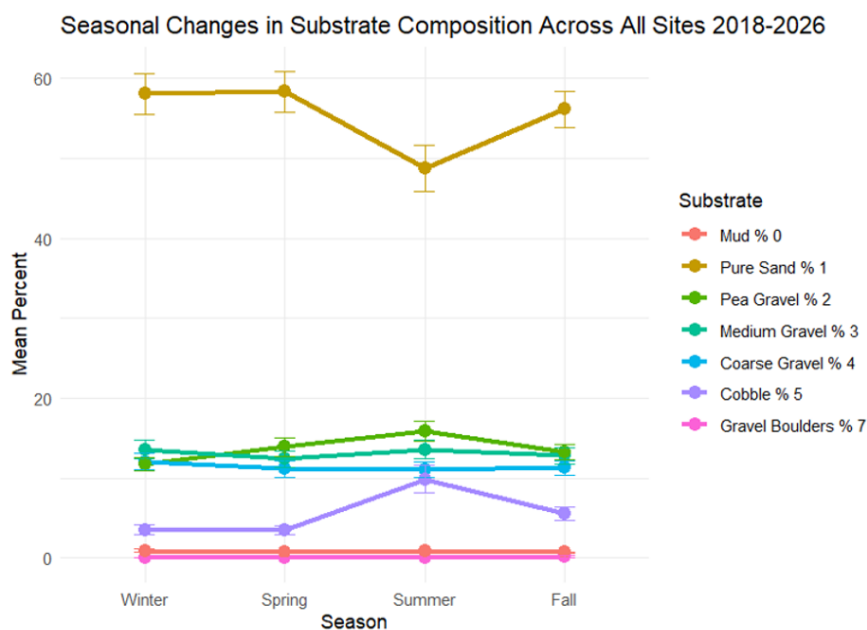


Fig 20. This figure displays seasonal changes in substrate composition across all data collection years for all three Snohomish County sites.

MRC Sampling Accuracy:

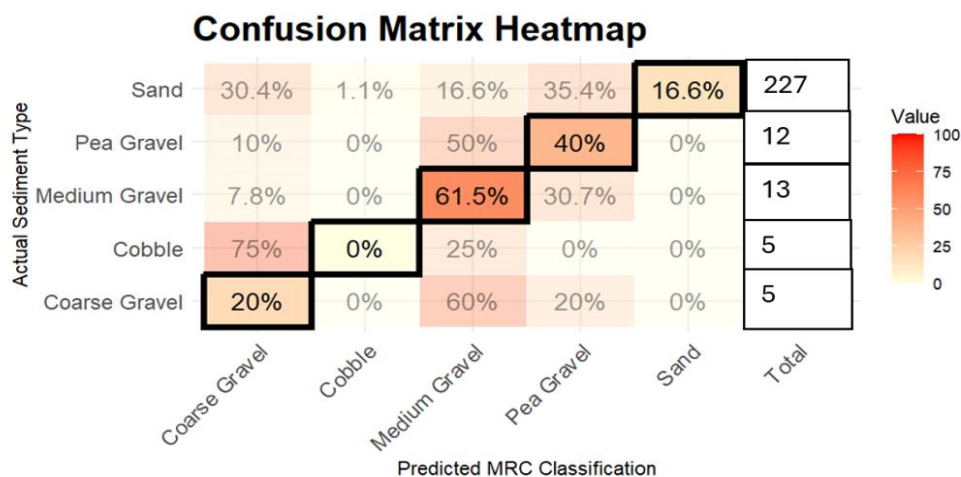


Fig 21. The heatmap shows actual sediment type vs MRC sediment classifications in the field for all sites spanning 2020-present. The bolded diagonal represents percentages of correctly classified sediments and the incorrect rankings for each class can be seen along subsequent rows.

See Appendix for additional heatmaps broken down by site (Figures 3-5)

Discussion:

Sediment composition differed significantly across Howarth, Picnic Point, and Meadowdale; however, these differences did not drive meaningful variation in forage fish spawning presence. This pattern is consistent with broader Puget Sound findings: substrate alone rarely predicts spawning, even on beaches that appear suitable.

Seasonality emerged as the strongest statistical driver of spawning activity. Surf smelt were detected primarily in fall, and sand lance exclusively in winter across Snohomish County beaches. These seasonal windows mirror long-documented Puget Sound patterns (Penttila 2007) and were reinforced by regional MRC observations. Seasonal restructuring of beaches is likely a contributor to these trends. During summer, sand content declines while coarser material like cobble increases, reducing suitable spawning substrate possibly aligning with decreased detections.

Table 3 Fig 22. Spawning Times Across Puget Sound where the Xs are when FF are found on SnoCo beaches (Shiley 2022).

General Spawning Times Across Puget Sound												
	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Pacific herring												
Sand lance	X	X										X
Surf smelt	X	X	X						X	X	X	X

Substrate analyses revealed complex and weak species–sediment relationships. Because grain-size percentages sum to 100%, sediment fractions are inherently interdependent, introducing multicollinearity that weakens model sensitivity. To address this, separate models were run for single fractions and grouped sediment classes. These refined models suggest that neither species relies on a singular grain size; instead, they use specific mixtures of sand, coarse sand, and small pea gravel.

For surf smelt, sand-only regressions indicated a weak negative trend, which sharpened when low-detection sites were removed. Medium gravel became the strongest positive predictor in the model of best fit, and presence peaked where sand percentages were relatively low. Sand lance showed a slight overall positive association with sand, but relationships became more interpretable after including all gravel types. Their presence was predicted higher with substrates enriched with coarse sands and small pea gravel, consistent with the contour plot showing high probabilities where these materials co-occur. Both species demonstrated this positive relationship with coarse sands and small pea gravel as well as negative associations with larger pea gravel. This was curious as literature notes SL utilize fine sand bases but there is likely more overlap between the two species than we think. Observations through Point No Point Treaty Council (PNPTC) reveal substantial spatial overlap in egg deposition between the two species suggesting shared habitat use though possibly differentiated by microhabitat or timing (PNPTC, 2018). These results highlight that forage fish respond to compositional blends of sediment rather than individual grain-size metrics and may have wider habitat or grain size utilization ranges than previously thought.

Spawning success appears to be influenced by factors beyond grain size alone. While substrate suitability contributes to spawning success, environmental and geomorphic conditions seem to play a larger role especially when it comes to site “selection”. Insights from the Island, Skagit, and Clallam MRCs indicate that their most productive beaches share features, including north-facing aspects and proximity to other productive sites. These clusters suggest that surrounding habitats provide proper sediment characteristics for burrowing, high prey availability, and positive feedback loops where survivorship and recruitment are consistently high resulting in these individuals likely spawning nearby contributing to future populations.

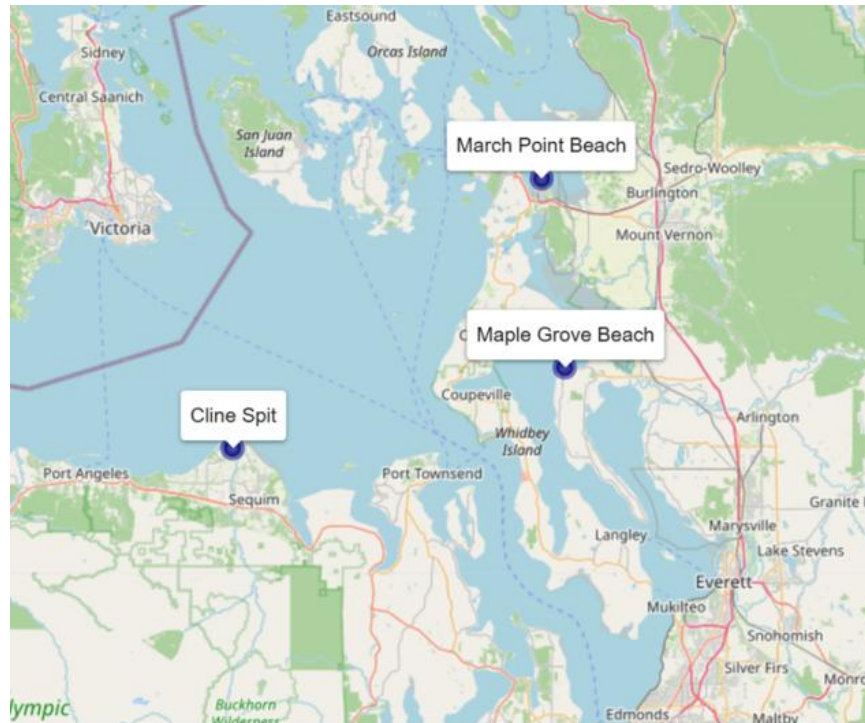


Fig 23. Map of prolific MRC monitored spawning beaches in Island, Skagit, and Clallam Counties.

Similar patterns were documented in Quinn and Penttila’s Camano Island study, where productive spawning areas aligned with broader habitat conditions and beach characteristics rather than just beach-level sediment grain size. This points to additional drivers potentially prey availability, circulation, and other nearshore processes aiding in recruitment “hot spots,” such as those historically observed on north Camano.

Quinn and Penttila’s Camano Island study demonstrated that the most productive beaches (42-49) had comparatively low maximum sediment temperatures, substantial fetch, narrow wood bands, and except for one site all had north-facing beach aspects. These environmental characteristics promote cooler substrates, favorable moisture retention, and consistent medium to high wave action within an optimal “goldilocks zone” of hydrodynamic energy. These sites all had variation in median sediment particle size, beach slope, backshore control type, and wood band volume.

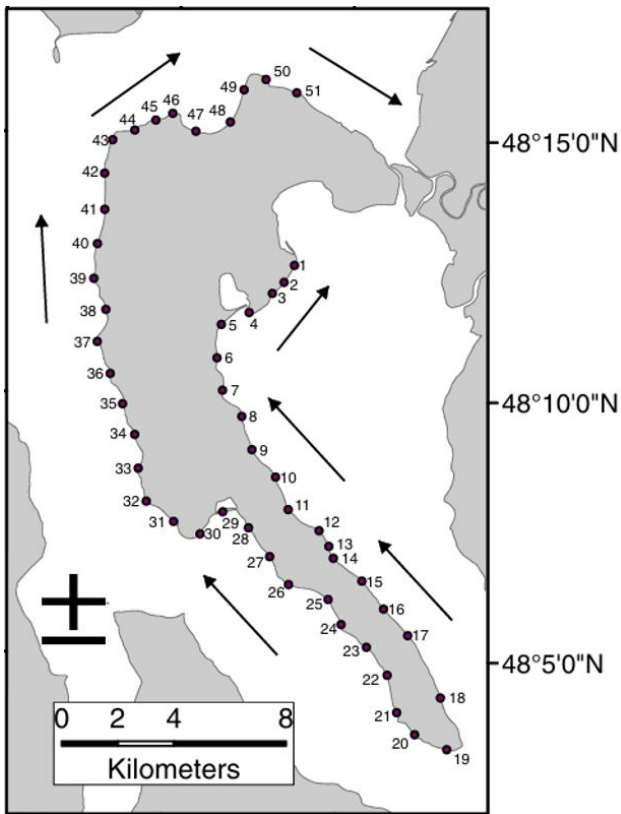


Fig 24. Map of Penttila and Quinn Camano Island Surf Smelt sites (Quinn et al., 2009).

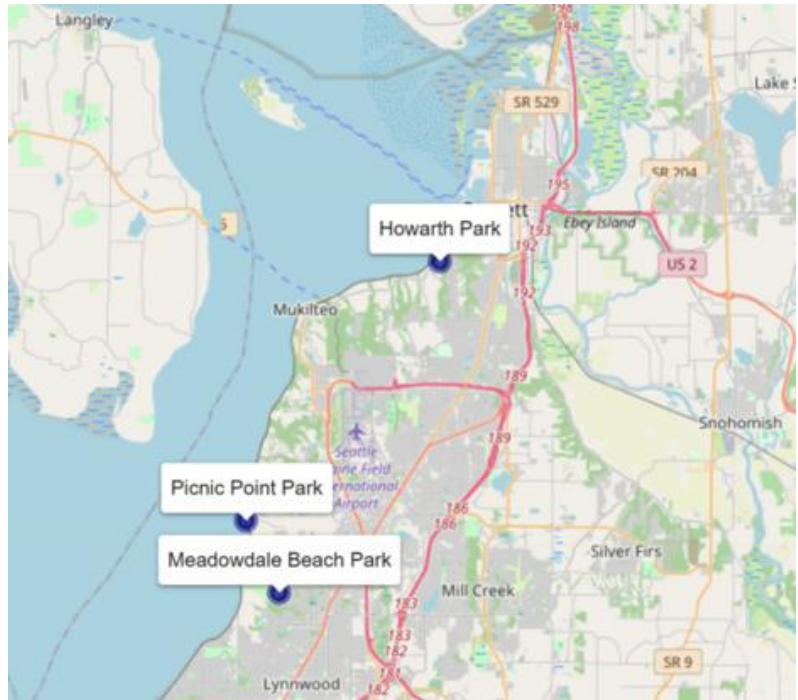


Fig 25. Map of Snohomish County MRC forage fish sampling sites

Several of these advantageous traits are present at Howarth Park, Snohomish County's most productive site. Its north-facing aspect, substantial fetch, and arrangement of woody debris align closely with the characteristics Quinn and Penttila identified as supporting spawning. Conversely, Picnic Point and Meadowdale lack these temperature-regulating advantages as they are both west facing and receive strong afternoon solar exposure. This directionality contributes to higher substrate temperatures, conditions known to elevate egg mortality.

The renourishment history at Howarth Park further illustrates why substrate manipulation alone does not reliably improve spawning habitat. Although large volumes of nourishment material were added in 2016, on-site spawning suitability did not increase for either sand lance or surf smelt. Slight improvements occurred only in downdrift areas where transported nourishment temporarily enhanced existing sandy zones, and even those benefits lasted only a few years (Lambert, 2023). Increases in spawning did not consistently match improvements in perceived substrate quality, however survivability of eggs could have improved and should be considered for future renourishments. However, this again indicates that forage fish respond more strongly to broader environmental conditions such as sediment temperature and quality, shading, potential wave action, and geomorphic setting rather than to grain-size characteristics alone.

The renourishment at Howarth points to drift cell positioning not only affecting sediment deposition processes but may also influence spawning locations. Beaches in northern Puget Sound could lie within drift cells that deliver eggs and juveniles to favorable rearing habitats, possibly supporting higher spawning intensity. Snohomish beaches may not benefit from similar transport pathways, but further mapping is needed to understand these dynamic processes.

It is also important to acknowledge the inherent variability and limitations of current survey methods. Many MRC partners reported that forage fish may be more present than detected, as the standard two-transect sampling design can easily miss small or patchy spawning areas. Penttila's Camano Island work demonstrated that expanded sampling efforts revealed eggs at beaches previously considered unproductive. This suggests that true spawning usage on Snohomish County beaches may be somewhat higher than detections indicate, though still likely less intensive than in northern Puget Sound regions especially for surf smelt.

Part of WDFW sampling protocol asks volunteers to classify or rank the sediment present at the sampling transect on a scale from 0-7. Mud or fine particles are considered a 0 traveling up the scale to 7 or gravel boulders and larger grain sizes. The heatmaps were created by identifying the dominate percentage and categorizing the sample as that dominant sediment type. Those "actual" classifications were then matched with the MRC observation for each sample. The heatmaps tell us how often MRC classifications were correct and show us when and how they were incorrect.

When sampling, Snohomish MRC members usually categorized sediment grain size a class above or below the "actual" sample type. I believe many of the incorrect categorizations were correct visually but simplifying sediment into one category is tricky and limits the compositions that are present. While understanding FF relationships with sediment is important, grain size is really more about survivability than selection for these populations.

Conclusion:

Forage fish spawning in Snohomish County is influenced more strongly by seasonal timing, physical beach characteristics, and microclimates rather than by specific grain-size or sediment-composition characteristics. While sediment composition differs significantly among sites, these differences do not reliably predict egg presence. Data suggest sand lance spawn primarily in winter with surf smelt spawning mainly in the fall both on mixed sand–small gravel substrates.

Spawning intensity in Snohomish County is low relative to other Puget Sound regions, and additional environmental factors like wood band distribution, drift cell position, sediment temperature, and fetch likely limit local suitability. This aligns with broader Puget Sound findings that substrate alone cannot explain spawning distribution.

If one takeaway emerges from this study it is that forage fish populations naturally undergo dramatic fluctuations in abundance and have for thousands of years (Washington Department of Fish & Wildlife, n.d.). The drivers of these fluctuations remain only partially understood and must be evaluated further. While Snohomish County may not be a major spawning hotspot, its beaches likely continue contributing to broader spawning stability, especially during fall and winter when other counties are less active. This continuation of spawning is of the utmost importance to keep recruitment high as emerging climate and human driven impacts like sea level rise and shoreline armoring squeeze and alter suitable spawning ranges (Krueger, 2010; Dethier 2010).

Recommendations:

Future work should expand beyond grain size analysis to investigate the broader suite of environmental variables identified across Puget Sound. Research into ideal sediment temperature bandwidths, beach aspect, drift cell positioning, wave action, and FF life histories would greatly improve understanding of forage fish spawning suitability.

Narrow wood bands stood out as a potentially alterable habitat feature that may improve dampness, shading, and aeration for intertidal eggs but are likely linked to wave action suitability more so, however this deserves further investigation as a practical restoration tool.

Incorporating beach-surface temperature measurements into forage fish surveys would help determine whether high solar exposure, particularly at west-facing beaches such as Picnic Point and Meadowdale, reduces suitable spawning windows. Such data may reveal subtle thermal constraints that WDFW and MRC members are interested in exploring through the deployment of long-term continual temperature monitoring sensors. Additionally, considering estimating percentages of substrate groups present during sampling could provide more holistic and specific substrate data rather than reporting an entire category as this generalizes sediment composition weakening the data.

Finally, increased collaboration within Snohomish County to examine habitat use across both estuarine environments and beach habitats could provide valuable life-history insights and potentially identify distinct population patterns across the county. Partnering with WDFW and the University of Washington for genetic analysis or broader spawning-pattern context could also reveal whether Snohomish County forage fish are connected to neighboring populations or represent distinct subgroups. Utilizing these partnerships also allows Snohomish County access to environmental and behavioral driver experiments as well as habitat improvement studies that may reveal more about spawning habitat usage. Additionally, partnering with Tulalip Tribes and regional MRCs to compare beaches, habitat usage, and environmental conditions remains essential. Such collaborations will strengthen long-term monitoring and help refine restoration strategies that better support forage fish populations.

Reference:

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Appendix:

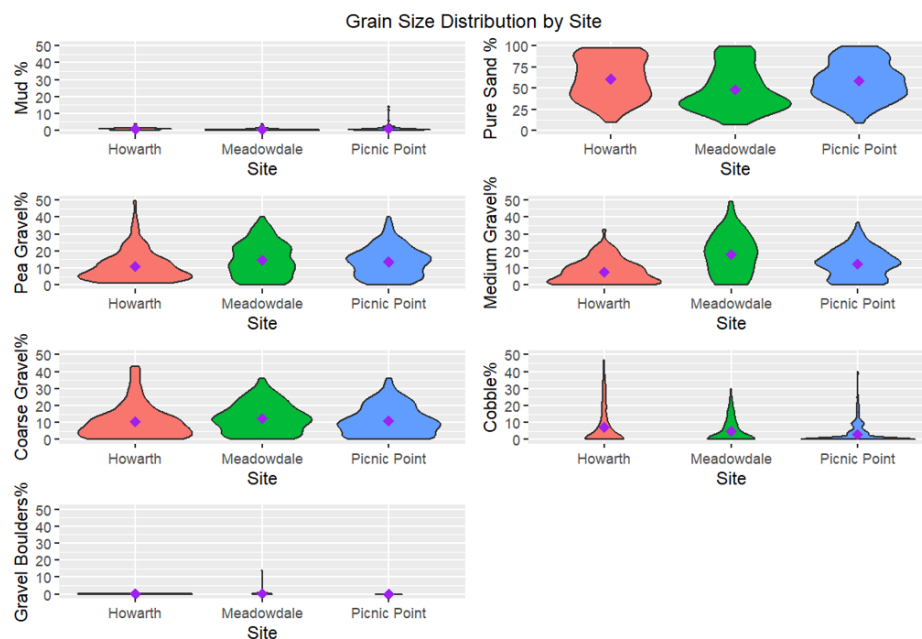


Fig 1. Grain size distributions by site where Picnic Point and Meadowdale range from 2018-2026 and Howarth 2018-2020. The width of each violin represents how frequently a percentage occurs, the shape shows how variable each substrate type is at each site.

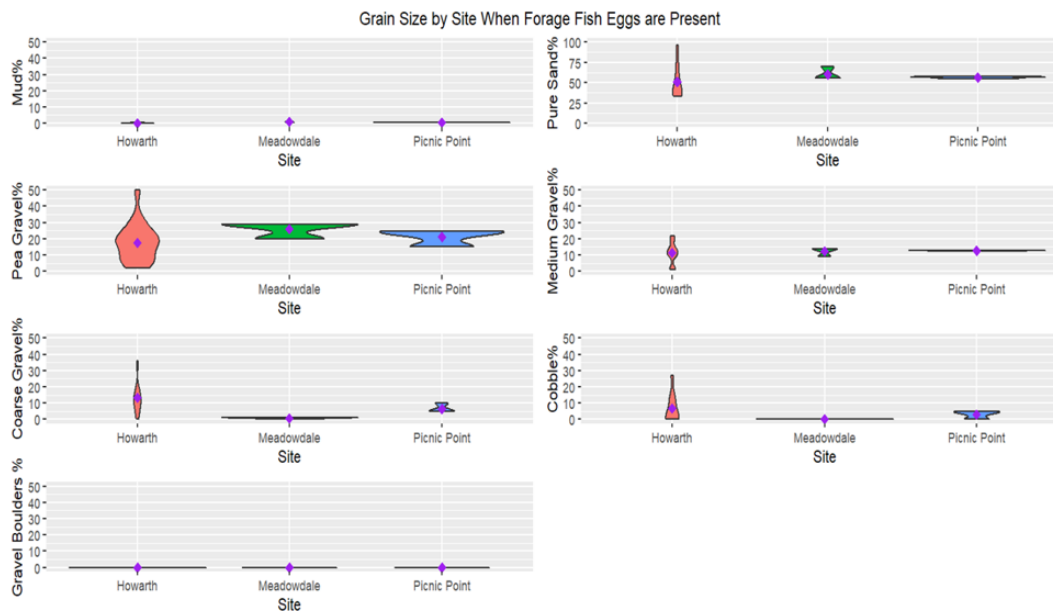


Fig 2. Grain size distributions by site when FF are present where Picnic Point and Meadowdale range from 2018-2026 and Howarth 2018-2020.

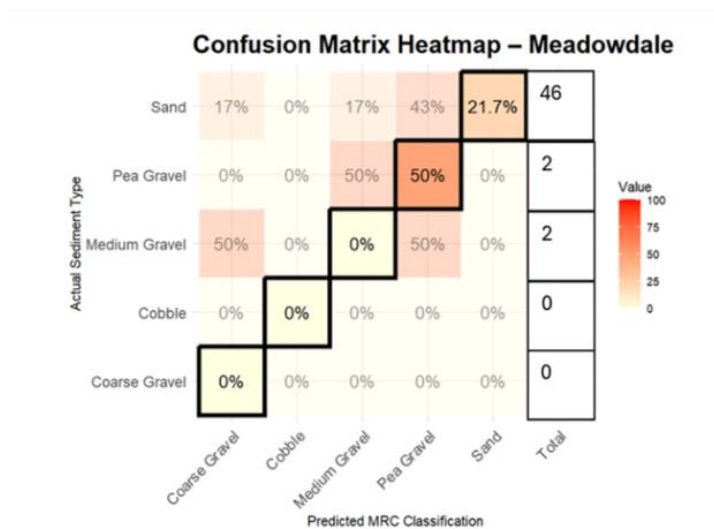


Fig 3. The heatmap shows actual sediment type vs MRC sediment classifications in the field for Meadowdale spanning 2023-present.

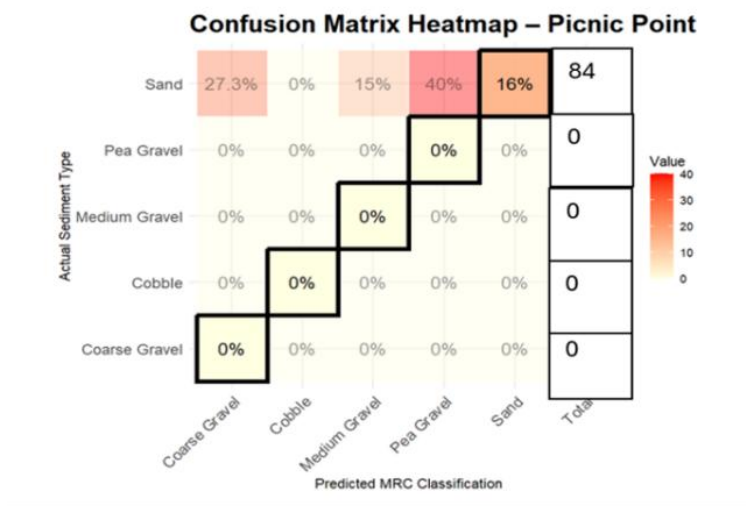


Fig 4. The heatmap shows actual sediment type vs MRC sediment classifications in the field for Picnic Point spanning 2020-present.

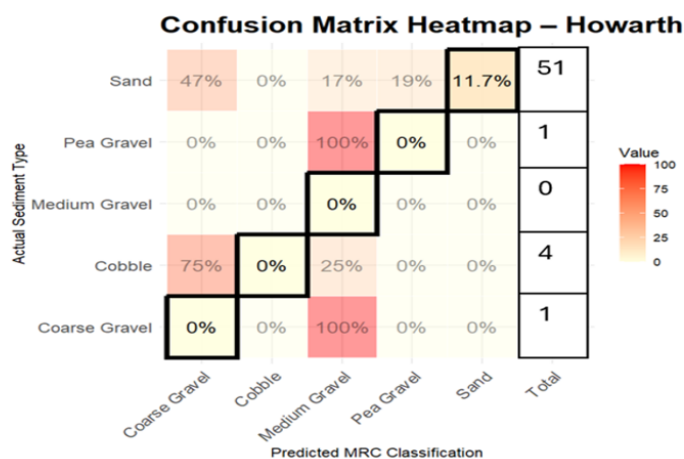


Fig 5. The heatmap shows actual sediment type vs MRC sediment classifications in the field for Howarth spanning 2020-2023.